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A multi-modal representation of El-Niño Southern Oscillation Diversity

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Sea surface temperature anomalies (SSTA) associated with the El-Niño Southern Oscillation (ENSO) show strong event-to-event variability, known as ENSO diversity. El Niño and La Niña events are typically divided into Eastern Pacific (EP) and Central Pacific (CP) types based on the zonal location of peak SSTA. The separation of these types is usually based on temperature differences between pairs of predefined indices, such as averages over boxes in the Eastern and Central Pacific or the two leading Principal Components of tropical SSTA.
Using results from unsupervised learning of SSTA data, we argue that ENSO diversity is not well described by distinctly separate classes but rather forms a continuum with events grouping into "soft'' clusters. We apply a Gaussian mixture model (GMM) to a low-dimensional projection of tropical SSTA to describe the multi-modal distribution of ENSO events. We find that El-Niño events are best described by three overlapping clusters while La-Niña events only show two "soft'' clusters. The three El-Niño clusters are described by i) maximum SSTA in the CP, ii) maximum SSTA in the EP, and iii) strong basin-wide warming of SSTA which we refer to as the "super El-Niño'' cluster. The "soft'' clusters of La-Niña correspond to i) anomalous cool SST in the CP and ii) anomalously cool SST in the EP. We estimate the probability that a given ENSO event belongs to a chosen cluster and use these probabilities as weights for estimating averages of atmospheric variables corresponding to each cluster. These weighted composites show qualitatively similar patterns to the typically used averages over EP and CP events. However, the weighted composites show a higher signal-to-noise ratio in the mid-latitudes for the "super El-Niño'' events.
We further apply our approach to CESM2 model data and discuss the potential of GMM clustering for evaluating how well ENSO diversity is captured in Global Circulation models.